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of Engineers

# LONG-TERM EFFECTS OF DREDGING OPERATIONS PROGRAM

TECHNICAL REPORT D-90-9

## FIELD EVALUATION OF THE QUALITY OF EFFLUENT FROM CONFINED DREDGED MATERIAL DISPOSAL AREAS: SUPPLEMENTAL STUDY — HOUSTON SHIP CHANNEL

by

Edward L. Thackston, Michael R. Palermo

Environmental Laboratory

DEPARTMENT OF THE ARMY  
Waterways Experiment Station, Corps of Engineers  
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199



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## PREFACE

This work was conducted as part of the Long-Term Effects of Dredging Operations (LEDO) Program at the Environmental Laboratory (EL), US Army Engineer Waterways Experiment Station (WES). The LEDO Program, sponsored by Headquarters, US Army Corps of Engineers (HQUSACE), is assigned to WES under the purview of EL's Environmental Effects of Dredging Programs. This report was written as part of LEDO Work Unit 31775, Techniques for Predicting Effluent Quality of Diked Containment Areas. The technical monitors were Drs. John Hall, William L. Klesch, and Robert Pierce, HQUSACE, and Mr. Charles W. Hummer, formerly of the Water Resources Support Center, Fort Belvoir, VA.

The study was conducted by and this report was written by Dr. Edward L. Thackston, Vanderbilt University, who participated under an Intergovernmental Personnel Act agreement, and Dr. Michael R. Palermo, Research Projects Group, Environmental Engineering Division (EED), EL. Dr. F. Douglas Shields, Dr. Paul R. Schroeder, and Mr. Daniel Averett, EED, were technical reviewers for this report.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)  
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI  
(metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
acres	4,046.873	square metres
acre-feet	1,233.489	cubic metres
cubic feet	0.02832	cubic metres
cubic yards	0.7646	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
gallons (US liquid)	3.785	cubic decimetres
inches	2.54	centimetres
miles (US nautical)	1.852	kilometres
pounds (mass)	0.4536	kilograms

FIELD EVALUATION OF THE QUALITY OF EFFLUENT FROM CONFINED  
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STUDY - HOUSTON SHIP CHANNEL

PART I: INTRODUCTION

Background

General

1. Confined dredged material disposal has increased in recent years, chiefly because of environmental constraints on the open-water disposal of sediments classified as polluted and unacceptable for unrestricted disposal. Release of contaminants in the effluent from confined disposal areas\* is dependent upon a number of factors relating to the physical, geochemical, and physicochemical characteristics of the dredged material and the variables of the confined disposal process. The term effluent is defined for purposes of this report as water that is discharged on a continuous or intermittent basis from confined disposal areas as they are being hydraulically filled during active disposal operations.

2. The effluent from confined disposal areas is considered a dredged material discharge under Section 404 of the Clean Water Act. Regulatory guidance and evaluation procedures have recently been developed to predict contaminant concentrations in effluents from confined disposal operations (Palermo 1986a, 1986b; Palermo and Thackston 1988a, 1988b, 1988c). These guidelines were also published as Environmental Effects of Dredging Programs Technical Notes (Palermo 1985). The field evaluation described in this report was conducted as a part of the overall study to provide further verification of the applicability of the procedures to specific situations in the field.

Description of processes  
influencing effluent quality

3. A confined disposal area is a diked enclosure used to retain dredged material hydraulically placed in the site. Confined disposal areas must be

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\* The terms confined disposal area, confined disposal site, diked disposal area, containment area, and confined disposal facility are used interchangeably in the literature.

designed to provide both adequate storage capacity for the settled sediments and efficient sedimentation to minimize the discharge of suspended solids (Montgomery, Thackston, and Parker 1983). Figure 1 shows the supernatant water interactions in an active confined disposal area. When hydraulic dredging occurs, the sediment is violently mixed with overlying water entrained by the dredge, and it is then subjected to sedimentation within the disposal area for a period ranging from a few hours to several weeks. Influent into the confined disposal site is a mixture of predominantly anoxic, chemically reduced sediment and aerobic entrained water from the overlying water column. Sedimentation results in a "thickened" deposit of settled material overlain by the clarified supernatant that normally contains dissolved oxygen. The physical and chemical conditions existing in both the sediment mass and the overlying water column prior to dredging are therefore subject to major changes, with resulting changes in contaminant mobility. Factors influencing the mobility of contaminants (e.g., from particle-associated to dissolved) include salinity, oxidation-reduction potential (Eh), hydrogen ion concentration (pH), and chemical composition of the interstitial water (Gambrell, Khalid, and Patrick 1976; Hoeppe, Myers, and Engler 1978). The physical properties of the sediment, including grain size distribution, clay mineralogy, and the presence of organic material, are also major factors.

4. The finer suspended particles are only partially removed from the supernatant water by sedimentation. Also, some of the settled particles reenter the supernatant water because of the upward flow of water through the slurry mass during compaction (or thickening). Wind-induced currents and/or surface wave action may also resuspend settled particles. All solids cannot be retained, and both dissolved and particle-associated contaminants are discharged in the effluent and transported to the receiving water. Design and operation of the disposal area, particularly the discharge weir or structure, also heavily influence the quality of the effluent. Methods for prediction of contaminant concentrations in the disposal area effluents were developed so that the potential for contaminant release and subsequent environmental impacts resulting from these activities may be properly predicted and evaluated.



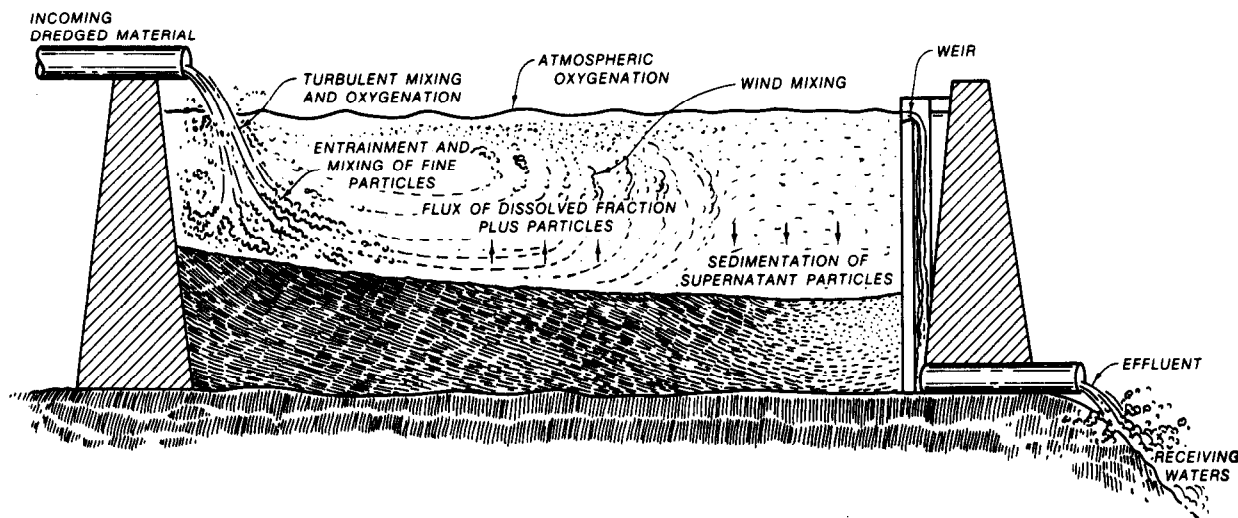


Figure 1. Schematic of ponded-water interaction in an active confined disposal site

### Purpose and Scope

5. The purpose of this report is to describe the results of a field evaluation of the method for predicting effluent quality for a dredging project on the Houston Ship Channel. This report is intended to supplement several previous studies (Palermo 1988; Palermo and Thackston 1988b). The predictive technique developed earlier is first briefly described for the reader's understanding of the methodology, followed by an explanation of the project and the field data collection process. The laboratory tests run on the sediment and water samples are described, and their resulting predictions are given. Finally, the measured field data are compared to the laboratory predicted effluent concentrations. These comparisons are discussed, and conclusions are drawn.

6. The original intent was to perform the study at a dredging site in a freshwater environment, because all previous verification studies have been at saltwater sites. Although initial information indicated fresh water in the upper reaches of the Houston Ship Channel, the water at the bottom of the channel was brackish at the time of the study. However, these comparisons serve as a further verification of the accuracy and precision of the predictive techniques under brackish water conditions (salinity greater than 3 percent), in which zone settling occurs. Another objective was to gather data

on the removal of manmade organic chemicals. Because the Houston Ship Channel was known to have been heavily polluted in the past, it was hoped that the sediments would contain sufficient quantities of manmade organics to be studied. This, however, did not prove to be the case. It is hoped that a future study can be made on organics at another site.

7. The field data include both dissolved and total concentrations of contaminants. Also included is a discussion of the efficiency of a confined disposal area containing a large amount of vegetative growth in retaining contaminants during active filling and effluent discharge operations.

8. Plots of individual contaminant concentrations as a function of time for both influent and effluent are presented in Appendix A. Summary plots of averages and standard deviations for both laboratory predicted concentrations and measured field concentrations are included in Appendix B.

## PART II: PREDICTION METHODOLOGY

9. A brief description of the predictive technique used on this process is provided here, before a description of the dredging project or the sampling and testing project, in order to give the reader an understanding of the laboratory and field data required to make validated effluent quality predictions. A description of the dredging project and field and laboratory sampling and testing follows in Parts IV and V and can be put in context more easily.

10. The prediction methodology for this and previous studies combines a modified elutriate test, a laboratory column settling test, and samples of both sediments and water from the proposed dredging site. Both tests will be briefly described in the following paragraphs, while more details can be found in the referenced articles and reports.

11. Any method for the prediction of the quality of effluent from confined dredged material disposal areas must account for both the dissolved concentration of contaminants and the solid contaminant fraction associated by adsorption or ion exchange with the total suspended solids (TSS) released. A modified elutriate test procedure recently developed for this purpose was used in making the laboratory prediction of effluent quality for this study (Palermo 1985, 1986b; Palermo and Thackston 1988a, 1988b). This test simulates the geochemical changes occurring in the disposal area during active disposal operations. The same test determines dissolved concentrations of contaminants in milligrams per litre and particle-associated contaminant fractions of the suspended solids in milligrams per kilogram of suspended solids under quiescent settling conditions.

12. Refinements and extensions of column settling test procedures (Montgomery 1978; Palermo, Montgomery, and Poindexter 1978; Palermo and Thackston 1988c) were also used to predict the concentration of suspended solids in the effluent for the given operational conditions at the Houston field site (i.e., ponded area and depth, inflow rate, and hydraulic efficiency). Using results from both the modified elutriate test and the column settling test, a prediction of the total concentration of contaminants in the effluent was made. Detailed procedures used for the predictions were given by Palermo (1985).

## Modified Elutriate Tests

### Procedures

13. Modified elutriate tests were conducted on the sediment samples taken from the channel prior to dredging using procedures described by Palermo and Thackston (1988a). These tests generally consist of the following steps:

- a. Mixing dredging site sediment and water to a concentration expected in the influent to the confined disposal site (the effluent from the dredge).
- b. Aerating the mixture for 1 hr to simulate the oxidizing conditions present at the disposal site.
- c. Settling the mixture for a time equal to the expected or measured mean retention time of the disposal area, up to a maximum of 24 hr.
- d. Extracting a sample of the supernatant water for analysis of dissolved and total contaminant concentrations. Detailed procedures for the modified elutriate test and a schematic of the test are presented in Appendix A.

### Selection of test factors

14. The modified elutriate test should be performed using a slurry concentration equal to that expected in the influent to the confined disposal site to be evaluated. The settling time used for the test should be equal to the mean field retention time in the confined disposal site, up to a maximum of 24 hr. These test factors must be known or assumed prior to conducting the tests. The modified elutriate tests for this field study were performed after the field monitoring and sample collection. In this way, field data on influent solids concentration and mean retention time were available prior to the tests, and these data were used as described in Appendix A in setting the test factors. Therefore, the comparisons of laboratory predictions and measured field data described in Part IV were not biased due to a poor selection of test factors. In a real prediction, these factors will not be known and must be predicted using the best available methods.

15. The field influent solids concentrations were determined from influent samples taken as described in Part III. The average influent concentration was used as a target concentration in making up the slurries for conducting the modified elutriate tests. Slurry concentrations in the laboratory can fluctuate with small variations in sediment sample water content. For

this reason, the slurry concentrations for the tests may vary somewhat from the target concentrations.

16. The field mean retention time was determined by a dye tracer test. At other sites, it may be estimated from the calculated or estimated theoretical retention time adjusted for the hydraulic efficiency normally associated with confined disposal sites. Procedures for estimating the retention times were described by Thackston, Shields, and Schroeder (1987). The field mean retention time determined from the dye tracer test was 8 hr, so this time was used in the modified elutriate test and column settling test.

#### Measurement of physicochemical parameters

17. Conductivity, dissolved oxygen concentration, and pH were measured in the field laboratory using instruments. All instrument readings were taken immediately upon sample extraction and processing.

#### Chemical analyses

18. All chemical analyses for this study were conducted according to standard procedures (American Public Health Association 1981). Metals analyses were performed using atomic adsorption spectrophotometers with heated graphite furnace. Nutrient analyses were performed using Technicon Auto Analyzers. Organic analyses were performed using high-resolution gas chromatograph/mass spectrometers. The Analytical Laboratory at the US Army Engineer Waterways Experiment Station (WES) performed the analyses.

#### Results

19. The chemical analysis of the modified elutriate samples provided the data used to predict dissolved and total concentrations of contaminant parameters in milligrams per litre. The total suspended solids concentration was also determined. To predict the total concentration of each contaminant in the effluent, it was necessary to first calculate the fraction of each contaminant associated with the total suspended solids in the elutriate samples. These fractions were calculated using Equation 1

$$F_{ss} = (1 \times 10^6) \frac{C_{total} - C_{diss}}{SS} \quad (1)$$

where

$F_{ss}$  = fraction of contaminant in the total suspended solids, mg contaminant/kg of suspended solids

$(1 \times 10^6)$  = conversion factor, mg/mg to mg/kg

$C_{\text{total}}$  = total concentration, mg contaminant/L of sample

$C_{\text{diss}}$  = dissolved concentration, mg contaminant/L of sample

SS = total suspended solids concentration, mg solids/L of sample

### Column Settling Tests

#### Procedures

20. Column settling tests on the composite sediment samples to predict the concentration of suspended solids in the effluent generally consist of the following steps:

- a. Mixing the dredging site sediment and water to a slurry concentration expected in the influent.
- b. Placing the slurry into an 8-in.-diam\* settling column and allowing it to settle.
- c. Taking samples of the supernatant water above the sediment-water interface that forms as settling progresses and repeating the process at various time intervals.
- d. Analyzing the samples for suspended solids concentration.

21. As with the modified elutriate tests, the measured field influent concentration for this study was known prior to the laboratory tests. This value was used as a target concentration for mixing the slurries for the settling tests. Detailed test procedures were given by Montgomery (1978) and Palermo (1985).

#### Prediction of effluent suspended solids

22. Using the column settling test results, prediction of the effluent suspended solids were made. The predictions were made by the following steps:

- a. Developing a relationship of column supernatant suspended solids versus settling time.
- b. Selecting a column supernatant suspended solids concentration corresponding to the expected mean field retention time.
- c. Determining a predicted effluent suspended solids value by adjusting the column value for wind and turbulence under field settling conditions. This adjustment can be made by using a settling efficiency adjustment factor, a function of ponded surface area and ponded depth (Palermo 1986a; Palermo and Thackston 1988c).

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\* A table of factors for converting non-SI units of measurement to SI (metric) units is presented in page 3.

Adjustment factors for  
turbulence and resuspension

23. The refined approach for prediction of effluent suspended solids previously described by Palermo and Thackston (1988c) assumes that the confined disposal area is well designed and operated, the weir has sufficient crest length, and ponding conditions do not allow resuspension of settled material. Good design assures adequate ponded surface area and sufficient storage for the zone settling process to concentrate the dredged material, if the entire slurry mass undergoes zone settling. However, the mean field effluent concentration of suspended solids for well-designed and well-operated sites would likely be higher than that indicated by quiescent laboratory tests.

24. The predicted values of effluent suspended solids is, therefore, normally considered the minimum value that can be achieved in the field under the best possible conditions for settling (i.e., little turbulence and little or no solids resuspension because of wind effects). Adjustment for turbulence and anticipated solids resuspension due to wind is appropriate for most cases.

25. The recommended approach in selecting appropriate settling efficiency adjustment factors is based on both anticipated ponded areas and ponding depths. The level of turbulence is related to advective flow velocities that are inversely proportional to ponded surface area and ponded depth for a given flowrate. However, wind can produce surface flow velocities in shallow, confined disposal areas that greatly exceed advective velocities (Poindexter and Perrier 1980). As the ponded area increases, the fetch distance for wind-induced waves increases, and the potential for solids resuspension also increases. As ponded depths and widths increase, the advective velocity is reduced. Increasing depth reduces the influence of wave action at the interface, and the potential for solids resuspension decreases. The recommended adjustment factors vary from 1.5 to 2.5 and are presented in Table 1 (from Palermo and Thackston 1988c). These settling efficiency adjustment factors are considered sufficiently conservative for purposes of disposal area evaluations under normally encountered wind conditions (excepting storms).

Laboratory Predictions of Effluent Quality

26. Predictions of the total contaminant concentrations in the effluent were made using the results of both the modified elutriate tests and column

Table 1  
Recommended Settling Efficiency Factors for Zone Settling Case  
(Salt Water) for Various Poned Areas and Depths

<u>Anticipated Poned Area</u>	<u>Anticipated Average Poned Depth</u>	
	<u>Less than 2 ft</u>	<u>2 ft or greater</u>
Less than 100 acres	2.0	1.5
Greater than 100 acres	2.5	2.0

settling tests. The predicted total concentrations are the sums of the predicted dissolved concentrations and the predicted particle-associated concentrations. Predicted dissolved concentrations are equal to those determined directly by the modified elutriate tests. Predicted particle-associated concentrations were calculated using the contaminant fractions of the total suspended solids determined by the modified elutriate tests and the predicted effluent suspended solids concentrations determined by the column settling tests. Using these tests results, the predicted total contaminant concentration in milligrams per litre in the effluent was estimated by Equation 2 as

$$C_{\text{total}} = C_{\text{diss}} + \frac{F_{\text{ss}} \text{ SS}_{\text{eff}}}{(1 \times 10^6)} \quad (2)$$

where

$C_{\text{total}}$  = estimated total concentration in effluent, mg contaminant/L of water

$C_{\text{diss}}$  = dissolved concentration determined by modified elutriate test, mg contaminant/L of sample

$F_{\text{ss}}$  = fraction of contaminant in the total suspended solids calculated from modified elutriate test results, mg contaminant/kg of suspended solids

$\text{SS}_{\text{eff}}$  = predicted suspended solids concentration of effluent estimated from evaluation of sedimentation performance in laboratory column settling test, adjusted for field conditions by factors from Table 1, mg suspended solids/L of water

$(1 \times 10^6)$  = conversion factor, mg/mg to mg/kg



### PART III: PROJECT DESCRIPTION

#### Project Location

27. The Houston Ship Channel is approximately 60 miles long, from the Gulf of Mexico near Galveston, TX, to near downtown Houston. The first 27 miles is in Galveston Bay, and the next 25 miles is through Buffalo Bayou to the main turning basin at the Port of Houston headquarters on Clinton Drive. A smaller channel, called the Light Draft Main Channel, runs westward for approximately 4 miles. This channel, plus the Turkey Bend Channel, an old bend now cut off and blocked at the upper end, were the sections dredged during this project.

28. The total length of the project was 22,283 ft, with 4,110 ft being in Turkey Bend. The location of the project is shown in Figure 2. Approximately 187,500 yd<sup>3</sup> was dredged by an 18-in. cutterhead dredge in August and September, 1988.

#### Disposal Area

29. The dredged material was placed in the Filter Bed Disposal Area on Clinton Drive just east of the Houston Belt and Terminal Railroad yards. The disposal area was approximately 1,100 ft by 3,200 ft, covering approximately 80 acres. It had been used several times in the past, and the bottom elevation had been built up to approximately 50 ft,\* about 30 ft above the surrounding terrain. It had not been used for about 15 years, and the interior was covered with vegetation, including trees up to 8 in. in diameter. About 10 acres in the southwest corner had been used to dump construction debris and was 8 to 10 ft higher in elevation.

30. For this project, the dikes were raised by borrowing material from a strip 100 to 200 ft wide just inside the dikes. Also, an area of approximately 20 acres in the northern end, the lowest part of the area, was cleared. The rest of the area was left undisturbed, and remained covered by vegetation, varying from cattail swamps to dense trees and brush. There were some

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\* All elevations (el) cited herein are in feet referred to National Geodetic Vertical Datum (NGVD) of 1929.

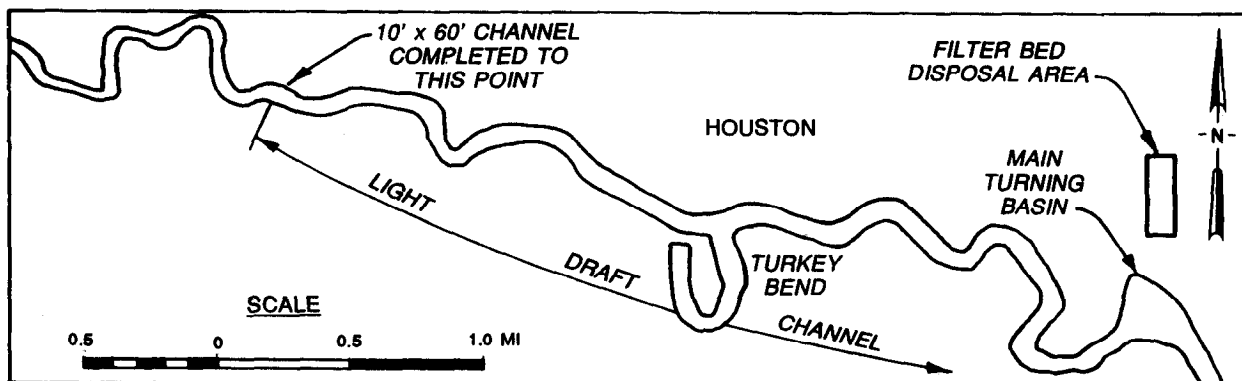


Figure 2. Project location

distinct internal drainage channels, including one through a culvert under an internal road.

31. An outlet consisting of a box with adjustable weirs on three sides was constructed near the northwest corner. A plan of the area is shown in Figure 3, and a photograph of the outlet structure before the area was filled, without the weir boards, is shown in Figure 4. A photograph showing how the weir boards were placed is shown in Figure 5.

32. Hydraulically, the disposal area was very inefficient. Only about 20 percent of the area was ponded, and much of the ponded area was to the east of the outlet weir and was past the outlet, therefore becoming essentially dead zone. The channel between the small ponded area in the southern end and the larger ponded dead zone was quite narrow and had high velocities and essentially no sedimentation. On the other hand, the southerly ponded area was covered by dense vegetation that slowed flow velocities, created numerous small quiescent dead zones, and enhanced sedimentation while also providing opportunities for adsorption and nutrient uptake.

33. Photographs of the area during the sampling period are shown in Figures 6 through 9. Figure 6 shows the southerly ponded area, looking north from the southeast corner. The east dike is on the right, and the ponded area extends into the swampy area in the woods on the left. Figure 7 shows the large mound of coarse sediments that formed a large delta area in the southeast corner during the previous 2 weeks of dredging. During the sampling period, the influent crossed this area by overland flow.

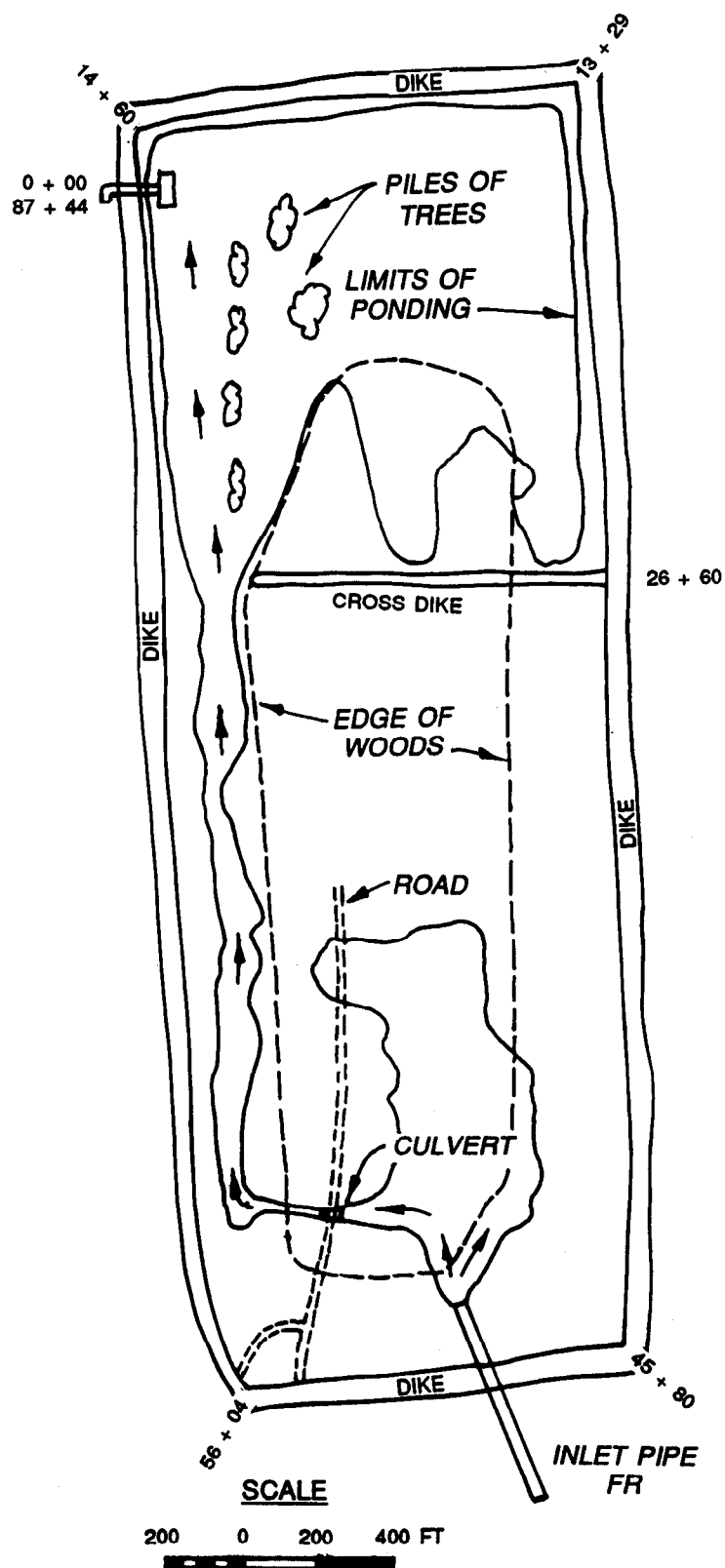


Figure 3. Plan of filter bed

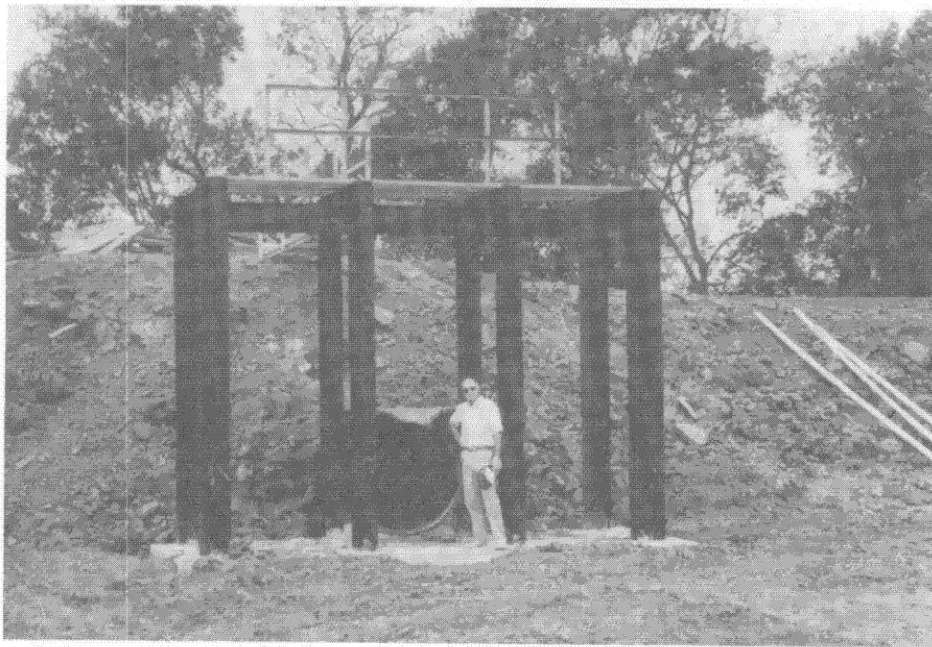


Figure 4. Outlet structure before filling



Figure 5. Outlet structure showing method of installing weir boards



Figure 6. Southerly ponded area, looking north  
from southeast corner



Figure 7. Southeast corner, looking southwest,  
showing delta formed by heavy sediments

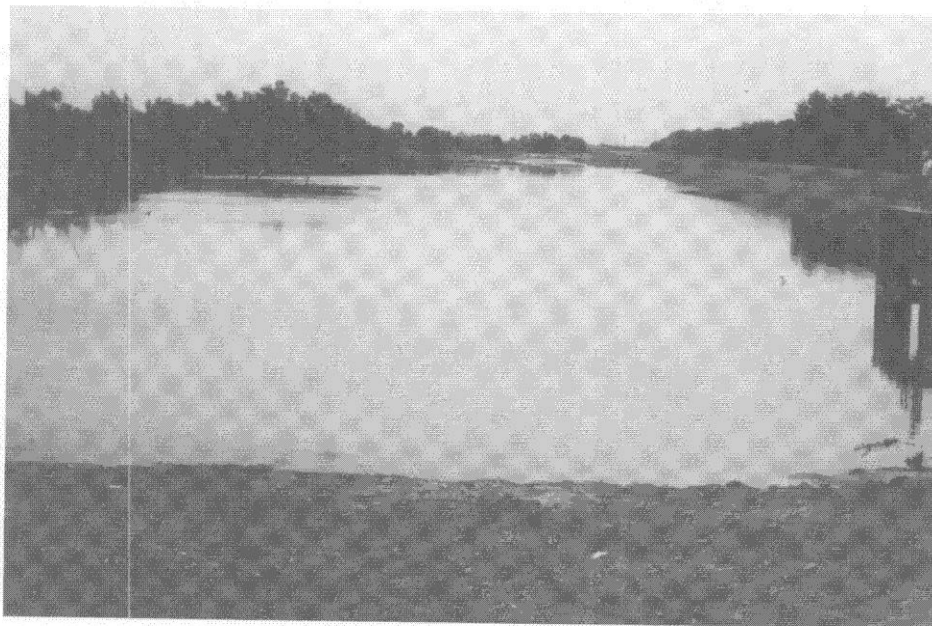


Figure 8. Ponded area in front of outlet structure, looking south from northwest corner

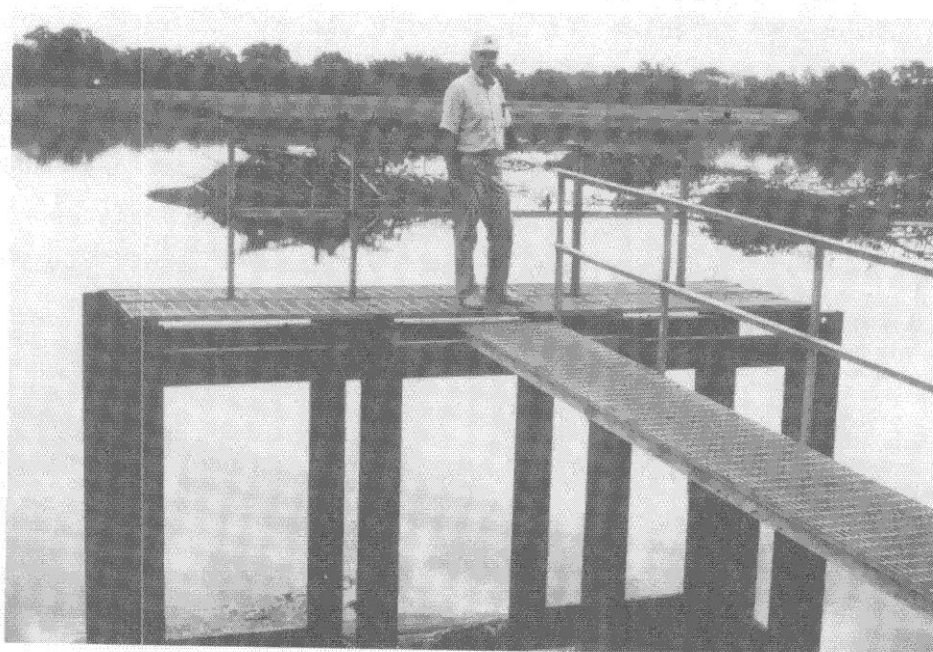


Figure 9. Northerly ponded area, looking east from northwest corner

34. Figure 8 shows the ponded area immediately adjacent to the outlet structure on the right of the photograph. Looking south, the west dike is on the right, woods on the left, and the well-defined channel carrying flow from the southerly ponded area to the northerly ponded area is in the background. Figure 9 shows the outlet structure and the northerly ponded area, looking east. Also shown are the piles of cleared brush and trees separating the area immediately adjacent to the outlet structure from the bulk of the northerly ponded area in the background, essentially a dead zone.

#### Dredging Operation

35. Field sampling for this study was conducted on August 10 and 11, 1988. During this period, the dredge was operating between stations 137 and 140, in the Turkey Bend Channel. This is only 700 ft from the end of the bend and about 16,000 ft from the disposal area. A construction materials firm is on the west bank at this point, and sand, shells, gravel, and cement from their operations had washed into the channel over the past 15 years. The combination of very heavy sediments and long pipeline length caused serious problems for the dredge. The pipeline plugged several times, but finally, an operational adjustment in which the cutterhead was raised every minute or so to pump clear water for a minute before lowering it again was adopted, and this allowed the dredge to proceed slowly. However, this method of operation resulted in much lower than normal average slurry concentrations (about 13 g/L versus 100 to 150 g/L normally), and the hydraulic resistance of the long pipeline resulted in lower than normal velocities (about 5 to 10 fps versus 12 to 18 fps normally).

#### PART IV: FIELD SAMPLING AND TESTING

36. This part of the report describes sampling and laboratory testing to predict effluent quality at the confined disposal site used for the field evaluation in this study. Part IV also documents the actual influent and effluent quality for comparison. Samples of sediment and water were collected and used to conduct modified elutriate and column settling tests. Results were used to predict both dissolved and total concentrations of contaminants in the effluent. Samples of the influent and effluent were tested, and the laboratory predictions are compared with measured field data in Part V.

37. Because this project was conducted for research purposes and to help validate the predictive procedures, all sampling and data collection was done at one time for the sake of simplicity and economy. Thus, "predictions" were not made until after the actual field data were collected. In routine operational use of this prediction technique, two field sampling operations would be necessary. The first would be for collection of water and sediment samples for the laboratory column settling test and the modified elutriate test prior to dredging. Then, after the data from these tests were used to make the predictions of effluent quality (perhaps leading to modification of the disposal area design), the dredging project would begin. Then, a second field sampling operation would be conducted to check the predictions and monitor compliance with discharge permits.

##### Dye Tracer Study

38. A dye tracer study was initiated at the same time as was sampling of the influent to the disposal area in order to provide an estimate of mean retention time, so sampling of the effluent could be lagged behind influent sampling by approximately that same length of time. In that manner, approximately the same parcel of water would be sampled, first at the influent, then at the effluent after it had been subjected to "treatment" in the disposal area (sedimentation, adsorption by plants, etc.).

39. Approximately 20 gal of Rhodamine WT fluorescent dye (20 percent solution, by weight in water) was poured into the swift, narrow stream leading away from the influent pipe at 0930 hr on August 10. Total injection time was



less than 5 min, and proper mixing was obtained because of the turbulent flow near the inlet.

40. Grab samples were taken approximately every half hour at the end of the discharge pipe from the weir box and analyzed within 15 min on a Turner Model 10 fluorometer. The results were plotted as a time-concentration (T-C) curve as the sampling proceeded. The concentration rose sharply at about 2.5 hr, peaked at 3.5 hr, and then declined slowly until about 8 hr, after which it dropped rapidly. The T-C curve is shown in Figure 10. As the T-C curve was being plotted, the mean retention time was estimated at about 10 hr, so effluent sampling was initiated at 1900 hr on August 10. The mean field retention time calculated from the centroid of the entire plotted part of the curve was approximately 8 hr. The actual mean retention time was probably slightly more, because the dye concentration had not quite returned to background at the termination of the test.

41. This shape of curve is indicative of extreme short-circuiting caused by a relatively direct flow path between inlet and outlet, with large amounts of dead zones off the main flow path. This behavior is consistent with the physical description of the site given earlier and observed behavior of the dye cloud.

42. The mean field retention time of 8 hr was calculated prior to conducting the modified elutriate tests described in Part II so that the estimated retention time could be used in setting the laboratory retention time for the tests. The 8-hr field mean retention time was used along with the column settling test results in estimating the effluent suspended solids concentrations.

#### Dredging Site Sediment and Water Sampling

43. The purpose of sediment and water sampling at the dredging site was to obtain adequate quantities of material for sediment characterization and for conducting the laboratory tests required for prediction of effluent quality.

##### Water sampling

44. Water samples for use in the laboratory tests were obtained using a positive displacement pump, with the intake within 1 m of the sediment-water interface. Care was taken to run the pumping apparatus for a sufficient

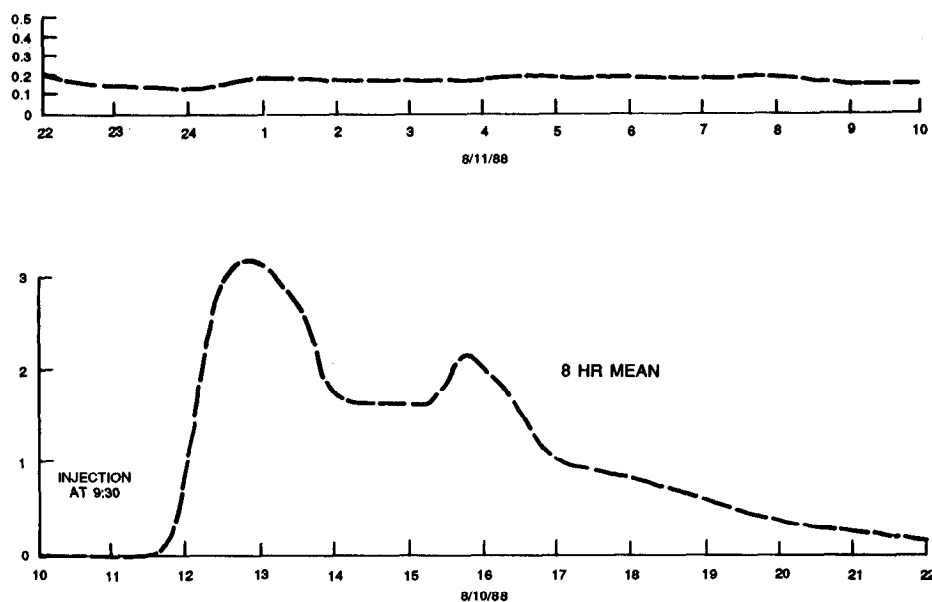


Figure 10. Time-concentration curve from dye tracer study

length of time to allow approximately three times the combined tube volume to pass through the system before the sample was collected (Plumb 1981). These water samples were taken so as to be representative of the water entrained during the dredging process.

#### Sediment sampling

45. Sediment samples for use in the modified elutriate and column settling laboratory tests were obtained using grab-type samplers. These samplers have proven adequate for obtaining samples from homogenous layers of bottom sediments associated with maintenance dredging activities and for accurately reflecting their in situ density and water content (Palermo, Montgomery, and Poindexter 1978). The samples were taken by repetitive grabs at the desired location in the channel until sufficient volume was obtained. The procedures that were used for sediment sample collection, handling, and preservation minimized sample contamination and preserved the physical and chemical integrity of the samples prior to testing (Plumb 1981).

46. Three 5-gal samples of sediment were taken with a grab sampler at about 1400 on August 10, when the dredge was at Station 137 in Turkey Bend. The three samples were taken approximately 50, 150, and 250 ft in front of the dredge, from the center of the channel. In the next 24 hr, the dredge moved

250 ft, covering the area sampled, so the samples were representative of the material placed in the disposal site during the field sampling. Dredging site water samples were also collected at the same time.

47. Samples of dredging site sediment and water were placed in prepared 5-gal airtight plastic containers. The containers were filled to the top to prevent any entrapment of air upon sealing. The samples were packed in ice and returned to the WES laboratory on August 12 and placed in a cold room. They were then composited and used to conduct the modified elutriate tests and laboratory column settling tests. Results of the analyses are tabulated in Table 2.

### Influent/Effluent Sampling

#### Variability problems

48. Many investigators have noted high variability in the influent into disposal areas (Krizek, Gallagher, and Karadi 1976; Hoeppel, Myers, and Engler 1978; Montgomery 1978; Palermo 1988) because of the heterogeneous nature of sediments and the operating characteristics of suction dredges. These sources of variability result in wide variations among influent suspended solids and contaminant concentrations. The influent pipe may discharge clear water at one instant and high suspended solids the next or sandy material one instant and fine silts or clays the next.

49. Contaminant and suspended solids concentrations in effluents discharged from confined disposal sites are less variable than influents because of the relatively long retention times and the mixing occurring within the disposal site.

50. Because of the highly variable influent and somewhat variable effluent, it was desirable to collect a large number of samples to provide a better estimate of the true mean contaminant and suspended solids concentrations. Based on the general examination of results of other studies of influent and effluent contaminant concentrations (Hoeppel, Myers, and Engler 1978), 50 samples was recommended as the preferred or ideal sample size for both influent and effluent sampling. However, it is usually impossible to obtain the preferred number of samples, especially for influent sampling, because of economic considerations, dredge breakdowns, weather, etc. The actual number of samples collected and analyzed for previous studies under this work unit

Table 2  
Dredging Site Sediment and Water Analyses - 1988  
Houston Ship Channel (Turkey Bend Site)

<u>Parameter</u>	<u>Sediment Concentration mg/kg</u>	<u>Water Concentration mg/L</u>
Total organic carbon	51,391	6.7
Ammonia nitrogen	305	0.66
Nitrate + nitrite nitrogen	10.8	1.73
Total phosphorus	1,360	1.24
Phosphate phosphorus	14.0	1.25
Cadmium	3.19	<0.0001
Chromium	80.9	0.007
Copper	64.4	0.004
Iron	20,600	0.379
Lead	96.2	0.029
Manganese	228	0.067
Mercury	1.35	<0.0002
Nickel	64.6	0.053
Zinc	725	0.042

Note: Very small quantities of PPDDE, dieldrin, heptachlor, methylene chloride, 1-4-dichlorobenzene, fluoranthene, pyrene, benzo (b) fluoranthene, benzo (k) fluoranthene, and indeno (1 2 3-C-D) pyrene were detected in the sediment. Only bis (2-ethylhexyl) phthalate was detected in the site water.

was usually about 25. In this study, 11 influent and 13 effluent samples were taken.

#### Sampling locations and schedules

51. Influent samples were taken directly from the dredge pipe discharging into the disposal area. A pipe with a 180-degree elbow and pointed guard to deflect rocks was used to collect the samples, and it proved effective. A photograph of the influent sampling point is shown in Figure 11. A total of 11 samples was taken over 11 hr. Only one sample had to be skipped or delayed because of dredge shutdown.



Figure 11. Influent sampling

52. Effluent samples were taken from the end of the pipe leading from the discharge weir box through the dike to a ditch to the west of the site. Thirteen samples were taken over a period of 18 hr. From visual observation, the flow was judged to be approximately constant during this period. A photograph of the effluent sampling point is shown in Figure 12.

53. The weather during the sampling period was hot and humid, with light and variable winds until about noon on August 11. A severe thunderstorm then hit the site. Effluent sampling was terminated 1 hr later.

54. The influent and effluent samples were tested within 20 min of sampling for temperature, pH, dissolved oxygen, and conductivity with instruments at a field laboratory provided by the Port of Houston. The samples were then packed in ice and transported to the WES laboratory for processing and analysis.

#### Chemical analyses

55. Due to funding considerations, the field evaluation described in this study was conducted during a regular maintenance dredging operation on the Houston Ship Channel. The parameters for analysis in the laboratory tests were chosen based on those determined to be of concern from a regulatory or



Figure 12. Effluent sampling

monitoring standpoint or on their presence as detected in earlier bulk chemical analysis of the sediments.

56. Previous chemical data for the dredging site sediments were available from a baseline study for environmental assessment purposes made in 1987 by the US Army Engineer District, Galveston. The bulk chemical composition of the sediments and the results of the standard elutriate tests were available. The bulk sediment concentrations were not used in making the predictions of effluent quality described in this part, but only in helping to identify those contaminants to be analyzed for during the field study. No organics were detected in the elutriates, and only small quantities of chlordane, benzo(a)pyrene, and fluoranthene in the sediments. Therefore, influent and effluent samples were not analyzed for organics during the field study. However, heavy metals were found in the 1987 elutriate analyses, so the 1988 field study concentrated on those contaminants.

57. The influent and effluent samples were analyzed for suspended solids and both total and dissolved concentrations of nutrients (total organic carbon, total phosphorus, phosphate phosphorus, ammonia nitrogen, nitrate nitrogen) and heavy metals (cadmium, chromium, copper, lead, mercury, nickel,

zinc, iron, manganese). The dissolved subsample was obtained by filtering the samples through a 0.45- $\mu$ m membrane filter.

58. Total concentrations of contaminants were determined for both influent and effluent at each site. This made possible the calculation of retention percentage of contaminants. Retention of contaminants within the disposal area was determined from the influent and effluent concentrations by Equation 3

$$R = \frac{[C_{inf}] - [C_{eff}]}{[C_{inf}]} (100) \quad (3)$$

where

R = retention in percent

$[C_{inf}]$  = total concentration in influent, mg/L

$[C_{eff}]$  = total concentration in effluent, mg/L

### Results

59. For each influent and effluent sample, the total and dissolved concentrations of each measured parameter (contaminant) were determined. These data, along with the suspended solids content of the sample, were used to calculate the contaminant fraction of the suspended solids for contaminants in each sample using Equation 1. The means and standard deviations for all measured parameters and each contaminant fraction are tabulated in Table 3. The means for the contaminant fractions were not calculated from the means of the suspended solids and contaminant concentrations but were calculated by averaging all of the calculated contaminant fractions of the individual samples. Results for the dissolved concentrations and calculated fractions in the total suspended solids for each containment are summarized in Table 3.

#### Suspended solids

60. Plots of the influent and effluent suspended solids concentrations are shown in Figure 13. The influent concentrations were typically highly variable, though much lower than typical, because of the peculiar operating procedure used by the dredge.

61. The effluent concentrations were relatively steady and low, typical of an effective disposal area. The mean concentration of suspended solids in

Table 3

Means and Standard Deviations for Total and Dissolved Concentrations of  
Parameters and Fractions in the Total Suspended  
Solids, Houston Ship Channel

Parameter	Total Concentration, mg/L				Retention Efficiency Percent	Dissolved Concentration mg/L			Fraction of Total Suspended Solids mg/kg SS		
	Influent		Effluent			Effluent			Effluent		
	Mean	Std Dev	Mean	Std Dev		Mean	Std Dev	Mean	Std Dev		
Total suspended solids	13,573	10,362	55.2	14	99.6	--	--	--	--	--	--
Conductivity, μmhos/cm	14,500		9,000		--	--	--	--	--	--	--
Dissolved oxygen	0.8		7		--	--	--	--	--	--	--
pH	7.25		7.8		--	--	--	--	--	--	--
Total organic carbon	14.5	6.7	13.6	1.5	6.2	12.4	3	21,744	55,656.37		
Ammonia nitrogen	9.25	6.77	25.8	3.224	--	23.2	6.754	38,432	118,415.22		
Nitrate + nitrite nitrogen	0.78	0.281	--		23.1	0.72		--	--		
Total phosphorus	24.8	17.4	1.31	0.195	94.7	0.78	0.211	9,848	4,658.37		
Phosphate phosphorus	21.2		0.99		95.3	0.72	0.201	4,797	3,609.37		
Cadmium	0.087	0.0652	0.00026	0.0004	99.7	0.00018	0.0001	4	11.05		
Chromium	1.86	1.40	0.007	0.002	99.6	0.0039	0.001	59	43.93		
Copper	1.46	1.14	0.0048	0.001	99.7	0.001	0.001	70	26.66		
Iron	300	237.9	1.36	0.195	99.5	<0.03	0	24,464	4,051.66		
Lead	16	10.56	0.0086	0.007	99.9	0.0036	0.004	92	142.53		
Manganese	5.11	2.97	0.49	0.029	90.4	0.42	0.114	1,015	2,092.59		
Mercury	0.025	0.0015	<0.0002	0	>99	<0.0002	0	0	0		
Nickel	1.10	0.789	0.0085	0.001	99.3	0.0185	0.012	0	0		
Zinc	13.9	10.68	0.042	0.01	99.7	0.018	0.015	306	249.71		



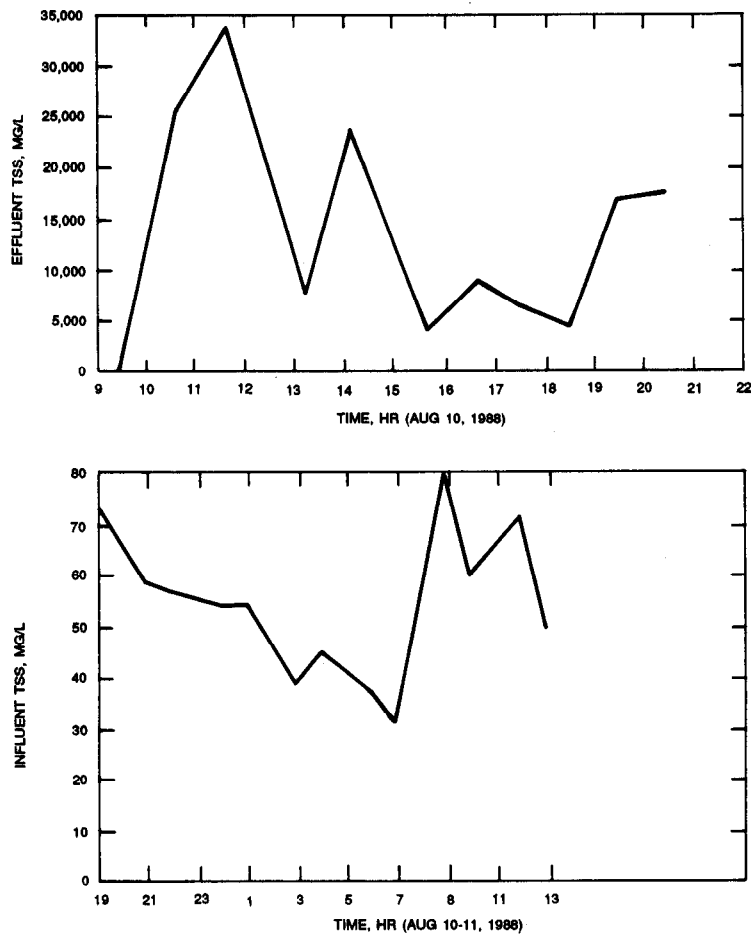


Figure 13. Total suspended solids variation

the influent was 13,570 mg/L, and the mean concentration in the effluent was 55 mg/L. This represents a good retention efficiency of 99.6 percent.

#### Conductivity

62. The mean influent conductivity was 14,500  $\mu\text{mhos/cm}$ , and the mean effluent value was 9,000  $\mu\text{mhos/cm}$ . Both were very consistent. The mean influent salinity was 8.2 ppt, about 25 percent the value of seawater, and the mean effluent value was 5.1 ppt. There is no present explanation for the effluent being significantly less saline than the influent, unless the disposal area was full of less saline water when the testing began. However, the effluent salinity fell slightly as the study proceeded, just the opposite of what one would expect to result from this explanation.

### Dissolved oxygen

63. The mean influent dissolved oxygen (DO) was 0.8 mg/L, and only 2 of 11 values were over 1.0 mg/L. They were associated with the two lowest values of suspended solids. The median value was 0.5 mg/L.

64. The mean effluent DO was 7.0 mg/L, with little variation. To indicate whether a significant portion of the dissolved oxygen entered the water during its fall over the weir and flow through the outlet pipe (the DO was measured at the exit from the pipe), the oxygen content was measured once at several places at one time during the first day of sampling. The oxygen content of the water in the disposal area directly outside the weir box was 4.7 mg/L; that inside the weir box was 5.8 mg/L; and that at the end of the weir box discharge pipe was 6.3 mg/L. This indicates that, while a significant part of the effluent DO entered the water during its flow through the outlet structure (approximately 25 percent), the water in the disposal area itself was also well oxygenated.

### pH

65. The mean pH of the influent was 7.25, with little variation. The mean pH of the effluent was 7.8, with slightly higher values during the first day and slightly lower values during the night and second day. This data pattern may indicate a slight amount of algal activity. This was also visually indicated by the fact that the water in the disposal area near the outlet structures had a green tint.

### Nutrients

66. The mean total organic carbon (TOC) content of the influent was 14.5 mg/L, and the mean value of the effluent was 13.6 mg/L, indicating little removal. Most TOC in the influent was in the dissolved form (86 percent) and presumably not subject to removal by sedimentation. Also, some soluble TOC was probably flushed from the swampy vegetated area by water flow through the disposal area, and a small amount could have been produced by algae growing in the disposal area.

67. The mean ammonia nitrogen content rose from 9.25 mg/L to 25.8 mg/L, indicating that some organic nitrogen was being partially degraded during its residence in the disposal area or that soluble ammonia nitrogen was being flushed out of the vegetated area. The mean value of nitrate plus nitrite nitrogen was reduced only from 0.78 mg/L to 0.60 mg/L. Both of these values are low, and nitrates are relatively unimportant in this situation.

68. The mean concentration of total phosphorus was reduced from 24.8 mg/L in the influent to 1.31 mg/L in the effluent (a 94.7-percent reduction), indicating good reduction but not nearly as great as the reduction in suspended solids (99.6 percent). This indicates that, while most of the phosphorus is associated with the suspended solids and is removed along with them, there is a significant amount in the dissolved form (0.78 mg/L in the effluent) or associated with the colloidal solids in the effluent that passed through the 0.45 $\mu$ m filter and was reported as dissolved. The pattern for phosphate phosphorus was very similar.

#### Heavy metals

69. All heavy metals were removed efficiently in the disposal area. All experienced removals of over 90 percent, and all except manganese experienced removals of over 99 percent. These data indicate that most heavy metals, except manganese, are closely associated with the suspended solids and are removed in a percentage closely approximating the percentage removal for suspended solids. Except for manganese, the heavy metals tested for were removed at percentages varying from 99.3 percent for nickel to 99.9 percent for lead, compared to 99.6 percent for total suspended solids.

## PART V: PREDICTION OF CONTAMINANT CONCENTRATIONS

### Results of Laboratory Tests

#### Modified elutriate tests

70. Three replicates of the modified elutriate test described in Part II were performed on sediment and water mixtures taken from the dredging site prior to dredging as described in Part IV. The sediment and water were mixed to a concentration of 13,500 mg/L, approximately the mean influent suspended solids concentration determined during the field study. The settling time was set at 8 hr, the mean retention time determined by the dye tracer test.

71. The three tests produced suspended solids concentrations of 83, 46, and 34 mg/L after 8 hr. The supernatant was analyzed for both dissolved and total concentrations of each contaminant according to the procedure outlined in Part II. The data resulting from the modified elutriate tests are tabulated in Table 4. The mean dissolved concentration found in the laboratory is the predicted dissolved concentration for the field. Each total concentration was used, along with its value of suspended solids, to calculate the contaminant fraction according to Equation 1.

72. To calculate the predicted total concentration of each contaminant according to Equation 2, the mean contaminant fraction was then multiplied by the predicted value of effluent suspended solids determined from the laboratory column settling test and the recommended settling efficiency factor, as described in Part II. The laboratory column settling test is described in paragraph 73.

#### Laboratory column settling test

73. A laboratory column settling test was performed according to the procedures outlined in Part II. The initial slurry concentration was set at 13,500 mg/L, approximately the mean influent suspended solids concentration determined during the field study.

74. The plot of mean supernatant suspended solids versus time is shown in Figure 14. At 8 hr, the mean retention time determined by the dye tracer test, the concentration was approximately 100 mg/L. This value was multiplied by the recommended settling efficiency adjustment factor of 1.5 from Table 1, because the ponded depth of the main body of water near the weir was greater

Table 4  
Results of Modified Elutriate Tests

<u>Parameter</u>	<u>Dissolved Concentration</u> mg/L		<u>Fraction of</u> <u>Total Suspended Solids</u> mg/kg of TSS	
	<u>Mean</u>	<u>Std Dev</u>	<u>Mean</u>	<u>Std Dev</u>
TOC	5.97	0.17	1,449	2,050
NH <sub>3</sub> - N	5.02	0.08	0	0
NO <sub>3</sub> + NO <sub>2</sub>	1.65	0.05	0	0
Total P	0.11	0.015	3,148	974
PO <sub>4</sub> - P	0.061	0.0019	1,368	181
Cadmium	<0.0001	0	0	0
Chromium	0.001	0	113	88
Copper	0.001	0	59	9.5
Iron	<0.03	0	9,287	950
Lead	0.0017	0.0005	364	319
Manganese	0.22	0.009	352	109
Mercury	<0.0002	0	0	0
Nickel	0.001	0	8.8	12.4
Zinc	0.031	0.0009	381	98

than 2 ft, and the area was approximately 10 acres, to arrive at the predicted field suspended solids concentration of 150 mg/L.

#### Predicted Contaminant Concentrations

75. The predicted value of suspended solids was then multiplied by each contaminant fraction, determined from the modified elutriate tests. The product was then added to the predicted dissolved concentrations, also from the modified elutriate tests, using Equation 2, to produce the predicted total contaminant concentrations.

76. The predicted dissolved contaminant concentrations are tabulated in Table 5, along with the measured mean field concentrations. The last column is the ratio of laboratory predicted concentration to measured field concentration. The predicted contaminant fractions of the suspended solids,

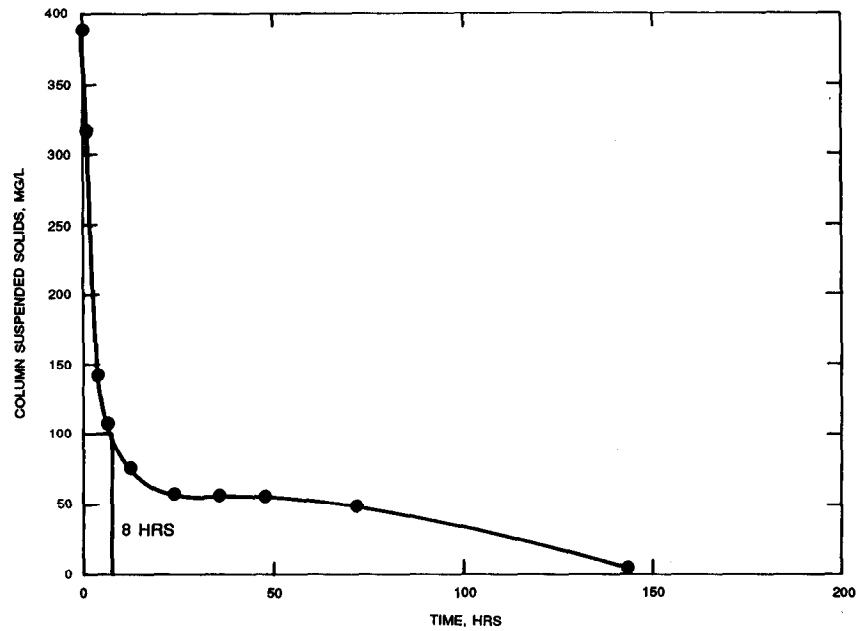


Figure 14. Plot of supernatant suspended solids in Houston Settling Test

determined in the modified elutriate test, are compared to the field-measured contaminant fractions in Table 6.

77. The predicted total contaminant concentrations are tabulated in Table 7, along with the measured mean field concentrations. Also included are the ratios of laboratory predicted concentrations to measured mean field concentrations.

Table 5  
Mean Measured and Predicted Dissolved Contaminants

<u>Parameter</u>	<u>Mean Measured Field Concentration mg/L</u>	<u>Mean Lab Predicted Concentration mg/L</u>	<u>Ratio of Predicted to Measured</u>
TOC	12.4	6.0	0.5
NH <sub>3</sub> - N	23.2	5.0	0.2
NO <sub>3</sub> + NO <sub>2</sub>	0.72	1.6	2.2
Total P	0.78	0.11	0.1
PO <sub>4</sub> - P	0.72	0.06	0.1
Cadmium	0.00018	<0.0001	0.5
Chromium	0.0039	0.001	0.3
Copper	0.001	<0.001	1.0
Iron	<0.03	<0.03	1.0
Lead	0.0036	0.0017	0.5
Manganese	0.42	0.225	0.5
Mercury	<0.0002	<0.0002	1.0
Nickel	0.0185	<0.001	0.1
Zinc	0.018	0.03	1.7

Note:

Mean ratio 0.7

Median ratio 0.5

9/14 ratios below 1.0; 4/5 nutrients, 5/9 metals

5/14 ratios equal to or greater than 1.0

8/14 ratios between 0.5 and 2.0

9/14 ratios between 0.33 and 3.0

Table 6  
Mean Measured and Predicted Contaminant Fractions

<u>Parameter</u>	<u>Mean Measured Field Fraction mg/kg</u>	<u>Mean Lab Predicted Fraction mg/kg</u>	<u>Ratio of Predicted to Measured</u>
TOC	21,745	1,449	0.1
NH <sub>3</sub> - N	38,432	0	0.0
NO <sub>3</sub> + NO <sub>2</sub>	0	0	1.0
Total P	9,848	3,148	0.3
PO <sub>4</sub> - P	4,797	1,368	0.3
Cadmium	4	0	0.0
Chromium	59	113	1.9
Copper	70	59	0.8
Iron	24,464	9,287	0.4
Lead	92	364	4.0
Manganese	1,015	352	0.3
Mercury	0	0	1.0
Nickel	0	9	-
Zinc	305	381	1.2

**Note:**

Mean ratio (omitting Ni) 0.9

Median ratio 0.4

8/14 ratios below 1.0; 4/5 nutrients; 4/9 metals

6/14 ratios equal to or greater than 1.0; 1/5 nutrients; 5/9 metals

6/14 ratios between 0.5 and 2.0

8/14 ratios between 0.33 and 3.0



Table 7  
Mean Measured Total Effluent Quality and Predicted Effluent  
Quality Based on Effluent TSS = 150 mg/L

<u>Parameter</u>	<u>Mean Field Concentration mg/L</u>	<u>Mean Predicted Concentration mg/L</u>	<u>Ratio of Predicted to Measured</u>
SS	55.2	150.0	2.7
TOC	13.6	6.18	0.5
NH <sub>3</sub> - N	25.8	5.02	0.2
NO <sub>3</sub> + NO <sub>2</sub>	0.60	1.65	2.7
Total P	1.31	0.58	0.4
PO <sub>4</sub> - P	0.99	0.27	0.3
Cadmium	0.00026	<0.0001	0.4
Chromium	0.007	0.018	2.6
Copper	0.0048	0.0098	2.0
Iron	1.36	1.39	1.0
Lead	0.0086	0.056	6.5
Manganese	0.49	0.28	0.6
Mercury	<0.0002	<0.0002	1.0
Nickel	0.0085	0.0023	0.3
Zinc	0.042	0.088	2.1

Note:

Mean ratio 1.6

Median ratio 1.0

7/15 ratios below 1.0; 4/5 nutrients; 3/9 metals

8/15 ratios equal to or greater than 1.0

5/15 ratios between 0.5 and 2.0

11/15 ratios between 0.33 and 3.0

## PART VI: DISCUSSION OF RESULTS

78. The data in Tables 5 through 7 show that the recommended method for predicting contaminant concentrations in the effluent from dredged material containment areas did a fair job from an overall standpoint, but individual predictions varied widely in accuracy. Both dissolved concentrations and contaminant fractions of nutrients were underpredicted, except for nitrates. Dissolved concentrations of heavy metals were either very accurate or underpredicted, while contaminant fractions predictions were quite variable. Predictions of total concentrations of heavy metals were quite variable, but the mean ratio of predicted to measured concentrations was near 1.0.

79. Some of the large deviation in ratios of laboratory predicted concentrations to measured field concentrations and contaminant fractions can be easily explained by the peculiar conditions at this site or by particular circumstances having to do with the analytical results, but others cannot be explained by the available data.

### Nutrients

80. Total organic carbon and ammonia nitrogen concentrations were both underpredicted, in spite of the suspended solids concentrations being overpredicted. Almost all of both nutrients were in the dissolved form, so the error in laboratory predicted contaminant fractions did not strongly influence the predicted total concentration. The effluent dissolved concentrations of these nutrients were so much higher than predicted probably because large quantities of dissolved and fine colloidal material already in the disposal area (in the swampy vegetated areas) were washed out by the flow of water through the area. Although contaminant fractions were widely underpredicted, an examination of the actual concentrations shows that they were quite large, with relatively small differences between total and dissolved concentrations. Therefore, small errors or inaccuracies in either could cause large changes in calculated contaminant fractions. The large overprediction of nitrate concentrations could be due to reduction and uptake of soluble nitrates by the large amount of vegetation in the disposal area. In addition, the original soils in the swampy vegetated area very likely remained anaerobic, at least in some areas, and nitrates in the water over these areas could have diffused into these

organic anaerobic sediments and been reduced to nitrogen gas. Because these sediments were not present in the modified elutriate test, this process was not simulated in the laboratory. Both of these processes would have lowered the effluent nitrate concentrations, leading to overprediction.

81. Both dissolved concentrations and contaminant fractions of phosphorus measured in the field were much greater than predicted, especially the dissolved concentrations. Almost all phosphorus was in the form of phosphate, usually tightly bound to solids. However, effluent data show that 60 percent of the total phosphorus and 73 percent of the phosphate was in the dissolved form. The tentative conclusion is that much of this phosphate is in fact adsorbed on fine colloidal particles that passed through the 0.45- $\mu$ m filter used to produce the dissolved subsample and is not truly in the dissolved form.

82. Although the effluent suspended solids concentration was somewhat lower than predicted, if much of the actual effluent suspended solids were in the form of very fine colloids with a low mass but high specific surface, this would explain the large errors in phosphorus predictions. These extremely fine colloids are the size particles that settle much more poorly in the field than in the lab column, where the quiescent conditions are much more conducive to colloidal flocculation and settling. Larger particles making up the bulk of the weight of suspended solids settle well in both environments, but the fine colloids settle better in the laboratory column. Previous data from other sites (Palermo and Thackston 1988b) also reveal that phosphorus concentrations and contaminant fractions were consistently underpredicted.

### Heavy Metals

83. The recommended prediction method did a very good job of predicting heavy metal dissolved concentrations, contaminant fractions, and total concentrations. Ratios of laboratory predicted to measured field concentrations of dissolved metals ranged from 0.5 to 1.0, except for chromium at 0.3, nickel at 0.1, and zinc at 1.7. All dissolved concentrations were extremely small, and most were close to the detection limit, so precision was not great, and large changes in ratios could result from small errors in analysis.

84. Contaminant fractions of metals were somewhat more variable in accuracy, but the mean ratio was 0.9, not counting that for nickel, which was

infinity (or indeterminate). The ratio for cadmium was zero, but the measured field contaminant fraction of 4 mg/kg is extremely small and is based on positive tests for cadmium in only 2 of 13 effluent samples. The measured field contaminant fraction for nickel of zero is based on the fact that effluent concentrations of total nickel were each slightly smaller than the dissolved concentrations. Both were quite low, however, so this anomaly can be attributed to analytical error.

85. The dissolved concentrations of heavy metals are probably of more importance, because dissolved metals are more readily bioavailable to aquatic plants and animals. Those associated with solids are more likely to settle to the bottom and again be incorporated into sediments, then to be covered by later sediments, sealing them off from most aquatic life. Although dissolved concentrations of heavy metals were slightly underpredicted in this study, this pattern is not consistently present in earlier data (Palermo and Thackston 1988b), so no change in methodology seems warranted.

## PART VII: CONCLUSIONS

86. The recommended method for predicting contaminant concentrations in effluent from dredged material containment areas has been shown again to provide generally accurate predictions. Mean ratios of laboratory predicted to measured field concentrations were near 1.0. Although some predictions were not exact and some ratios were quite different from 1.0, some instances are due to the particular local circumstances of this study, and others are based on extremely small concentrations and, therefore, perhaps imprecise analyses. In these later cases, concentrations of contaminants discharged are so small they are negligible in most cases.

87. More research is needed to fully define relationships between contaminant concentrations and size distribution of particles. This would help explain some inconsistencies in predictions, especially those relating to nutrients, and perhaps lead to improvements in methods and more accurate and more consistent predictions. In the meantime, only one consistent underprediction has been identified as a result of the current procedure. Both in these and previous results, it has been noted that predicted concentrations of dissolved phosphate and total dissolved phosphorus are underpredicted by a factor of 4.0, possibly due to the fact that much colloidal phosphorus (measured as dissolved phosphorus) appears in the field effluents but not in the modified elutriate test because of better settling of fine colloids in the laboratory test. With that exception, it can be concluded that this study furnished further verification of the validity, accuracy, and usefulness of the predictive method, especially when the highly unusual local conditions are considered.

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APPENDIX A: PLOTS OF INFLUENT AND EFFLUENT  
CONTAMINANT CONCENTRATIONS

Plots of influent and effluent dissolved and total concentrations and contaminant fractions are reproduced on microfiche in the back cover of this report.



APPENDIX B: SUMMARY OF PLOTS OF MODIFIED ELUTRIATE  
AND EFFLUENT CONTAMINANT CONCENTRATIONS

Summary plots of modified elutriate and effluent contaminant concentrations are reproduced on microfiche in the back cover of this report.

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16. SUPPLEMENTARY NOTATION (Continued).

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. Plots of influent and effluent dissolved and total concentrations and contaminant fractions and summary plots of modified elutriate and effluent contaminant concentrations are reproduced on microfiche in the back cover of this report.

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